

Correction to the article "Dynamic power management in energy-aware computer networks and data intensive computing systems" published in "Future Generation Computer Systems" journal

Andrzej Karbowski

Institute of Control and Computation Engineering, Warsaw University of Technology, ul. Nowowiejska 15/19, 00-665 Warszawa, Poland, E-mail: A.Karbowski@elka.pw.edu.pl

Abstract

This paper indicates two errors in the formulation of the main optimization model in the article "Dynamic power management in energy-aware computer networks and data intensive computing systems" by Niewiadomska-Szynkiewicz et al. and shows how to fix them.

Keywords: energy-aware network, energy-aware routing, traffic engineering, dynamic power management, data intensive computing

1. Introduction - the original model

The paper [1] presents an in-depth study of the energy-aware traffic engineering in TCP/IP networks. Authors have proposed therein an inspiring model of energy-aware router, an architecture of a control framework and various formulations of a network-wide energy saving optimization problem. They start from the exact mixed integer programming (MIP) formulation, which is aimed at solving the problem of a minimum energy routing. The objective is the minimization of the total power utilized by network components while ensuring end-to-end Quality of Service (QoS). The basic link-node formulation (*LNPb*) is a network management problem with binary decision variables describing full routing in a network and corresponding energy state assignments to all routers, line cards and communication ports.

More precisely, the hierarchical network model proposed in [1] considers every single communication port $p \in \{1, \dots, P\}$ of every line card $c \in \{1, \dots, C\}$ of a router $r \in \{1, \dots, R\}$. The links connecting pairs of ports are denoted by $e \in \{1, \dots, E\}$; any network component can operate in $k \in \{1, \dots, K\}$ energy state, but two ports connected by a link are in the same state. A demand $d \in \{1, \dots, D\}$ is characterized by its source s_d , the destination t_d port nodes and the volume V_d .

The topology of the physical network is described by four matrices of binary indicators: $l_{cp}, g_{rc}, a_{ep}, b_{ep}$, whether, respectively: port p belongs to the card c , card c belongs to the router r , link e is outgoing from the port p and link e is incoming to the port p .

The decision variables are two vectors of binary indicators x_c, z_r - whether the card c or router r is used for data transmission and two incidence matrices with elements: y_{ek} - whether the link e is in the state k and u_{ed} - whether the demand d uses the link e .

The full optimization problem presented in [1] is as follows:

$$\min_{x_c, y_{ek}, z_r, u_{ed}} \left[F_{LNPb} = \sum_{r=1}^R T_r z_r + \sum_{c=1}^C W_c x_c + \sum_{e=1}^E \sum_{k=1}^K \xi_{ek} y_{ek} \right], \quad (1)$$

subject to the constraints:

$$\forall_{e=1,\dots,E} \sum_{k=1}^K y_{ek} \leq 1, \quad (2)$$

$$\forall_{\substack{d=1,\dots,D, \\ c=1,\dots,C}} \sum_{p=1}^P l_{cp} \sum_{e=1}^E a_{ep} u_{ed} \leq x_c, \quad (3)$$

$$\forall_{\substack{d=1,\dots,D, \\ c=1,\dots,C}} \sum_{p=1}^P l_{cp} \sum_{e=1}^E b_{ep} u_{ed} \leq x_c, \quad (4)$$

$$\forall_{\substack{r=1,\dots,R, \\ c=1,\dots,C}} g_{rc} x_c \leq z_r, \quad (5)$$

$$\forall_{\substack{d=1,\dots,D, \\ r=1,\dots,R, \\ p=s_d}} \sum_{c=1}^C g_{rc} l_{cp} \sum_{e=1}^E a_{ep} u_{ed} - \sum_{c=1}^C g_{rc} l_{cp} \sum_{e=1}^E b_{ep} u_{ed} = 1, \quad (6)$$

$$\forall_{\substack{d=1,\dots,D, \\ r=1,\dots,R, \\ p \neq t_d, p \neq s_d}} \sum_{c=1}^C g_{rc} \sum_{p=1}^P l_{cp} \sum_{e=1}^E a_{ep} u_{ed} - \sum_{c=1}^C g_{rc} \sum_{p=1}^P l_{cp} \sum_{e=1}^E b_{ep} u_{ed} = 0, \quad (7)$$

$$\forall_{\substack{d=1,\dots,D, \\ r=1,\dots,R, \\ p=t_d}} \sum_{c=1}^C g_{rc} l_{cp} \sum_{e=1}^E a_{ep} u_{ed} - \sum_{c=1}^C g_{rc} l_{cp} \sum_{e=1}^E b_{ep} u_{ed} = -1, \quad (8)$$

$$\forall_{e=1,\dots,E} \sum_{d=1}^D V_d u_{ed} \leq \sum_{k=1}^K M_{ek} y_{ek}, \quad (9)$$

where M_{ek} and ξ_{ek} are, respectively, the capacity and the power consumption of the link e in the state k , and W_c and T_r are power cost coefficients of the card c and the router r .

Unfortunately, there are some errors and deficiencies in this novel formulation. They are pointed out in the next section and followed by suggestions how to fix them. Without these changes the model does not describe well the dependencies between different components of the energy-aware computer networks and data intensive computing systems, including routers, cards, ports and links and is not fully useful.

2. Errors in the original model and their correction

There are two errors in the formulation (1)-(9):

1. Flow conservation equations (6)-(8) are incorrectly written.

First of all in Eqn. (7) there is a redundancy in using the index p - at the beginning it is assumed fixed, while in the middle it is used as the index of a summation operator. In this equation, as well as in Eqs. (6), (8), p should not be a fixed parameter, because in computer networks ports are only labeled inputs to routers - nodes, where the switch of routes is done. Every port in a router can be an input or an output for signals and the summation over them and, at the same time, over all links outgoing and incoming to the router, should be performed in Eqs. (6), (8) as it is in (7).

2. Despite the announcement in subsection 4.1 of the article [1]: "Two ports connected by the eth link are in the same state k . " there are no equations ensuring it. The conditions (9) expressing the energy used by links are formulated independently for all links.

The above assumption is natural in computers networks and it should be reflected in a good model.

To fix the two errors mentioned above it is proposed:

Ad.1. To replace the three equations (6)-(8) by the following general one:

$$\forall_{\substack{d=1,\dots,D, \\ r=1,\dots,R}} \sum_{c=1}^C g_{rc} \sum_{p=1}^P l_{cp} \sum_{e=1}^E (a_{ep} - b_{ep}) u_{ed} = \begin{cases} 1 & r = s_d, \\ -1 & r = t_d, \\ 0 & \text{otherwise.} \end{cases} \quad (10)$$

In this equation the summation is done across every router $r = 1, \dots, R$ for every demand $d = 1, \dots, D$. All links connected to the router r are taken into account owing to the summations:

$$\sum_{c=1}^C \sum_{p=1}^P \sum_{e=1}^E g_{rc} l_{cp} a_{ep} u_{ed} \quad (11)$$

for the outgoing traffic and

$$\sum_{c=1}^C \sum_{p=1}^P \sum_{e=1}^E g_{rc} l_{cp} b_{ep} u_{ed} \quad (12)$$

for the incoming traffic.

Ad.2. To augment the conditions (9) with equality constraints assuring that the energy level in both links of every edge is the same. They are as follows:

$$\forall_{\substack{p=1,\dots,P \\ k=1,\dots,K}} \sum_{e=1}^E a_{ep} y_{ek} = \sum_{e=1}^E b_{ep} y_{ek} \quad (13)$$

Since in equation (13) indices p and k are fixed, with the assumptions taken, for a given port p^* there is only one combination of links $e_1, e_2 \in 1, \dots, E$, such that:

$$a_{e_1 p^*} = b_{e_2 p^*} = 1, \forall_{e \neq e_1} a_{e, p^*} = 0, \forall_{e \neq e_2} b_{e, p^*} = 0. \quad (14)$$

Taking this into account from equation (13) we will get for all $k = 1, \dots, K$:

$$y_{e_1 k} = y_{e_2 k} \quad (15)$$

The same reasoning may be repeated for the opposite port p^{**} of the edge, such that:

$$b_{e_1 p^{**}} = a_{e_2 p^{**}} = 1, \forall_{e \neq e_1} b_{e, p^{**}} = 0, \forall_{e \neq e_2} a_{e, p^{**}} = 0. \quad (16)$$

It means, that the energy level will be the same in the edge formed of links e_1 and e_2 .

The corrected model will have the form¹:

$$\min_{\substack{x_c, y_{ek}, z_r, u_{ed} \\ c \in \overline{1, C}, e \in \overline{1, E}, k \in \overline{1, K} \\ r \in \overline{1, R}, d \in \overline{1, D}}} \left[F_{LNPbC} = \sum_{e=1}^E \sum_{k=1}^K \xi_{ek} y_{ek} + \sum_{c=1}^C W_c x_c + \sum_{r=1}^R T_r z_r \right], \quad (17)$$

subject to the constraints:

$$\forall_{\substack{d=1,\dots,D, \\ c=1,\dots,C}} \sum_{p=1}^P l_{cp} \sum_{e=1}^E a_{ep} u_{ed} \leq x_c, \quad (18)$$

¹We added all sets of indices of the arguments of optimization and their domains, incorrectly omitted in [1].

$$\forall_{\substack{d=1,\dots,D, \\ c=1,\dots,C}} \sum_{p=1}^P l_{cp} \sum_{e=1}^E b_{ep} u_{ed} \leq x_c, \quad (19)$$

$$\forall_{\substack{r=1,\dots,R, \\ c=1,\dots,C}} g_{rc} x_c \leq z_r, \quad (20)$$

$$\forall_{e=1,\dots,E} \sum_{k=1}^K y_{ek} \leq 1, \quad (21)$$

$$\forall_{\substack{d=1,\dots,D, \\ r=1,\dots,R}} \sum_{c=1}^C g_{rc} \sum_{p=1}^P l_{cp} \sum_{e=1}^E (a_{ep} - b_{ep}) u_{ed} = \begin{cases} 1 & r = s_d, \\ -1 & r = t_d, \\ 0 & \text{otherwise,} \end{cases} \quad (22)$$

$$\forall_{e=1,\dots,E} \sum_{d=1}^D V_d u_{ed} \leq \sum_{k=1}^K M_{ek} y_{ek}, \quad (23)$$

$$\forall_{\substack{p=1,\dots,P \\ k=1,\dots,K}} \sum_{e=1}^E a_{ep} y_{ek} = \sum_{e=1}^E b_{ep} y_{ek}, \quad (24)$$

$$x_c, z_r \in \{0, 1\} \quad c = 1, \dots, C; r = 1, \dots, R; \quad (25)$$

$$y_{ek}, u_{ed} \in \{0, 1\} \quad e = 1, \dots, E; k = 1, \dots, K; d = 1, \dots, D. \quad (26)$$

3. Conclusions

The paper fixes two errors in the basic formulation of the optimization problem in the study [1]. To make the model correct it was necessary to modify the flow balance equations, treating routers as nodes (instead of ports as it is in [1]) and to add equality constraints on the levels of power consumption in two links incoming to and outgoing from the same port.

Acknowledgments

Before publication in Arxiv.org this paper was submitted to "Future Generation Computer Systems" journal and rejected by the Editor-in-Chief with the words "Notwithstanding the quality of your paper, I had to reject it. The reason being that FGCS receives a tremendous amount of manuscripts and we need to select the ones that are most urgent and of relevant importance to our

readership. Your paper falls currently outside that scope and has not been forwarded to reviewers.”.

It means that FGCS journal neglects a fundamental in science right to critics. Mistakes or errors are not so rare in scientific publications and the proper approach is to point them and, if possible, to fix them, e.g. [2], [3]. A journal editorial board cannot decline responsibility for the quality of the published material.

References

- [1] E. Niewiadomska-Szynkiewicz, A. Sikora, P. Arabas, M. Kamola, M. Mincer, J. Kołodziej, Dynamic power management in energy-aware computer networks and data intensive computing systems, *Future Generation Computer Systems*, 37 (2014) 284–296.
- [2] S. Low, E. Lapsley, Optimization flow control, I: Basic algorithm and convergence, *IEEE/ACM Trans. on Networking*, 7(1999) 861-874.
- [3] A. Karbowski, Comments on ”Optimization Flow Control, I: Basic Algorithm and Convergence”, *IEEE/ACM Trans. on Networking*, 11(2003) 338–339.